



Monitoring urban physical growth in tsunami-affected areas: a case study of Banda Aceh City, Indonesia

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Accepted: 11 December 2020 / Published online: 2 January 2021
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Abstract Building back better-based urban planning is an integral part of efforts to increase urban resilience. Therefore, urban physical growth needs to be monitored to prevent built-up areas from expanding into hazard zones. This study analyzed the dynamics of urban physical growth and its driving forces in tsunami-affected areas of Banda Aceh after the 2004 tsunami. Built-up areas were extracted from Landsat images. The annual growth rate equation was used to estimate the growth characteristics in the tsunami-affected and safe areas. In-depth interviews and extensive literature reviews were also conducted to identify the determinant factors of urban redevelopment in tsunami-affected areas. Results showed that the annual growth rate was high in the areas during the disaster recovery period (2005–2009). Nevertheless, urban physical growth dominated in the safe areas during 2009–2019. The study also identified several driving forces of urban physical growth in the hazard zones: (1) population growth, (2) spatial planning, (3) distance to old city center, (4) land ownership and prices, and (5) socio-economic factors. This study provided new insights for urban planners to reduce disaster risk in urban areas.

Keywords Urban physical growth · Tsunami · Driving force · Banda Aceh

Introduction

Urbanization is a crucial issue in urban studies today, considering that most of the world population lives in urban areas. Urban population continues to increase and is predicted to reach more than 60% by 2030 (United Nations 2019). This trend can be followed by the rapid transformation of landscapes to urban land cover (Seto et al. 2012). However, urban growth often leads to hazard zones, especially if it is not controlled by appropriate spatial planning (Chang et al. 2012). Moreover, the occurrence of disasters is difficult to predict and control, which can cause widespread short and long-term impacts.

Urban planning provides an opportunity to control urban growth so that risks can be minimized. Integration of risk reduction in urban management has two outcomes, namely, protection of new and existing buildings or infrastructures, and avoidance of new risks through current and future urban development (ADPC 2013). In this regard, several methods can be applied. Integration can be initiated through hazard zone assessment, which is then translated into a form of land use regulation (Asian Development Bank 2016), such as the application of coastal buffers to

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prevent coastal hazards, prohibition of occupancy in areas prone to volcanic eruptions, and establishment of protected areas on riverbanks to avoid flood hazards. This strategy can be combined with policies related to building codes, incentive mechanisms, determination of evacuation routes, and other structural or non-structural measures. The successful implementation of urban planning based on disaster risk management is also determined by the support between stakeholders, emphasizing the importance of participatory approach (Rizzi and Porebska 2020).

Urban growth is basically influenced by various determinant factors or driving forces. Natural hazards should be an inhibiting factor for urban growth. However, these factors sometimes do not prevent the expansion of built-up areas, especially in developing countries. Urban development can even re-occur in hazard zones even though disasters have occurred in the area. Hamdy et al. (2016) found that government policy is a driver of urban growth in the Abouelreesh flood hazard zone in Egypt. Rimal et al. (2017) observed that urban growth in the Kathmandu valley earthquake zone in Nepal is influenced by population growth and the availability of urban facilities. Tyas (2018) stated that low-income groups are trapped in a flood-prone area of Semarang in Indonesia because of economic reasons. Huang et al. (2019) also analyzed that population growth accelerates urban expansion in the most seismically hazardous area of China. These results highlight the importance of raising awareness and preparing for a more resilient city, which is also a core principle of sustainable urban planning.

Tsunami is classified as one of the shocks for urban communities (Matsuoka et al. 2009). Despite its relatively low frequency of occurrence, this type of disaster has the potential for highly destructive impacts. At least five large-scale tsunami events have caused significant damages in various cities in the past 20 years (2000–2019): 2001 in Peru, 2004 in several countries around the Indian Ocean, 2010 in Chile, 2011 in Japan, and 2018 in Indonesia (EM-DAT 2019). Most cities affected by the tsunami face the open sea and subduction zones. The 2004 tsunami caused the most fatalities and damages, especially in Aceh Province, Indonesia. The death toll reached 226,408 people and the damage cost was nearly US \$10 billion. The number of fatalities caused by the 2011 tsunami in Japan was not as high as that caused by the 2004 tsunami (19,846 lives), although the

magnitude of the earthquake in the two events was similar. However, the total damage was very high (US \$210 billion) because of the many buildings that were damaged, coupled with the incidents of damage to the Fukushima Nuclear Power Plant (Khazai et al. 2011; EM-DAT 2019). Recently, a tsunami occurred in Palu, Indonesia in 2018. The mechanism of the tsunami was unusual because it originated from a strike-slip fault, its epicenter was on land, and local factors were involved (Arikawa et al. 2018). Urban planning that does not prioritize risk reduction was considered to have contributed to the magnitude of losses due to the tsunami disaster.

Banda Aceh, the capital of Aceh Province, experienced significant damage because of the 2004 Indian Ocean Tsunami. The inundation area reached more than 60% of the city at that time. Japan International Cooperation Agency reported that the city lost a third of the population, thousands of people were dislocated due to the disaster, and 44,544 houses were damaged or destroyed (JICA 2005). The magnitude of the tsunami's hydrodynamic forces caused the collapse of the main bridge and heavy damage to public facilities and roads in the coastal area; other urban infrastructures, such as communications, water supplies, drainages, and fuels, were also damaged (Ghobarah et al. 2006). Considering the wide scope of impact and the paralyzed functions of local government, the Indonesian Government declared it a "national disaster", prompting a large number of international donors to offer humanitarian assistance. Several urban recovery efforts were carried out on a massive scale to restore the function of the city as the center of government and economy in Aceh Province.

The 2004 tsunami provided valuable lessons for the scientific community and decision-makers, demonstrating the importance of incorporating disaster risk management into urban planning. However, the urban physical growth after a disaster still needs to be observed to prepare a resilient city. This finding is in line with the principle of building back better (BBB), which has received increasing attention since the disaster (Clinton 2006). Although urban physical growth has been analyzed in Banda Aceh (Achmad et al. 2014; Arief and Itaya 2018; Amri 2020; Amri and Giyarsih 2020), its association with the specific growth conditions and factors in tsunami-affected zones remains unknown. Therefore, this study focuses on monitoring the dynamics of urban physical growth

and its driving forces in tsunami-affected areas of Banda Aceh after the 2004 tsunami. The city was chosen as a research location to explore the extent to which the BBB concept can be applied in urban planning after a catastrophic disaster. This research could be used to predict urban vulnerability while helping the government evaluate urban growth to achieve urban resilience.

Urbanization and disaster risk

Urbanization is a process of becoming urban. Urban growth as part of urbanization is currently receiving major attention along with the increase in population in urban areas. Most of the population has occupied urban areas since 2007 and is expected to continue to increase along with the expansion of urban settlements (United Nations 2019). Low-income countries would also have the fastest rate of urbanization going forward. This condition is an outcome of a combination of rural to urban migration, natural urban population growth, and reclassification of rural areas (Farrell 2017).

An urban area usually experiences multi-direction expansion, which can reach areas prone to disasters. This situation can occur in developing or developed countries, but unplanned rapid urbanization is more common in developing countries than in developed countries. Conceptually, vulnerability is directly proportional to risk. Thus, the vulnerability in urban areas is certainly higher than that in rural areas because of the concentration of population, infrastructure, and strategic facilities. However, urban risks also depend on the extent of capacity building to cope with and adapt to hazards. For example, Coburn et al. (2015) predicted that the magnitude of economic loss in cities in developed countries is the greatest if a disaster occurs. However, the proportion of economic loss is greater in developing country cities than in developed country cities. The death rate due to disaster is also greater because of poor risk governance and ineffective management (Dickson et al. 2012).

At present, the urban risk of disasters is increasing along with urban growth that continues naturally. Gu (2019) found more than 1000 cities with 300,000 inhabitants highly exposed to at least one type of natural hazard. The world megapolitan cities (cities with a population of more than 10 million) that are

concentrated around the coastline (e.g., Tokyo, Mexico City, Dhaka, and Jakarta) are highly vulnerable to coastal hazards. Some of them can even be exposed to multi-hazards. The impact of climate change makes the risk of hydrometeorological disasters even worse because of sea-level rise and increasing extreme weather intensity. Other threats are geological disasters (earthquakes, volcanic eruptions, and tsunamis) that can destroy cities suddenly, especially those around the Ring of Fire (Iuchi and Esnard 2008). Environmental degradation triggered by human activities also increases the risk of disasters in urban areas (Guadagno et al. 2013).

The 2004 Indian Ocean Tsunami proved that catastrophic disasters pose a threat to cities where their growth did not pay attention to aspects of natural hazards. Many coastal cities were hit by the tsunami waves and caused significant death and damage at that time. The 2004 tsunami has opened a window of opportunity for the development of disaster risk reduction in Indonesia and throughout the world (Djalante et al. 2012). Disaster management in Indonesia specifically experienced a paradigm shift after the 2004 tsunami, where risk reduction efforts began to become a major concern.

At the same time, BBB was introduced as a foundation in post-disaster recovery programs to increase community resilience by improving physical and socio-economic aspects (Clinton 2006). Furthermore, it is represented by three concepts: risk reduction, community recovery, and implementation (Mannakkara and Wilkinson 2012). This term has been applied in the 4th key priority of the Sendai Framework for Disaster Risk Reduction 2015–2030. Although the meaning of “better” itself is still being debated, it is increasingly mentioned in contemporary disaster studies, especially concerning disaster recovery (Fernandez and Ahmed 2019). In this study, the term “BBB” is focused on physical development (especially urban expansion) and is used to assess whether or not urban recovery for safe development is achieved.

Research method

Study area

Banda Aceh is located in the northern part of Sumatra Island, Indonesia with an area of 59 km². Geographically, the city is bordered by the Malacca Strait to the north, Aceh Besar District to the south and east, and the Indian Ocean to the west (Fig. 1). The city consists of nine sub-districts (*kecamatan*), namely, Meuraxa, Jaya Baru, Banda Raya, Baiturrahman, Lueng Bata, Kuta Alam, Kuta Raja, Syiah Kuala, and Ulee Kareng. The topography is relatively homogeneous and flat with an average elevation of 0.8 meters above sea level. The natural landform genesis is influenced by fluvial and marine processes (Umitsu et al. 2007), and the city location is close to the Sumatra subduction zone, making it prone to multiple natural hazards (including tsunamis). The population density is relatively high with the population reaching 270,321 inhabitants in 2019 (BPS Kota Banda Aceh 2020).

The 2004 tsunami inundated most of Banda Aceh City area. In the eastern part of the city, the tsunami wave penetrated up to 5 km across the Aceh River Floodway. Areas along the 2–3 km of the shoreline experienced total destruction. Among the nine sub-districts, Meuraxa and Kutaraja were the worst affected by the tsunami because the population mostly lived in the coastal area, while Banda Raya, Lueng Bata, and Ulee Kareng did not experience any significant losses (JICA 2005). Since that time, the safe zones have been prioritized for new urban development. Thus, this study divides the research location into two parts, namely tsunami-affected areas and safe areas, to provide an overview of the dynamics of urban physical growth in the two thematic zones.

Land cover mapping

This study analyzes the dynamics of urban physical growth in two periods: 2005–2009 (formal disaster recovery) and 2009–2019 (post-disaster recovery).

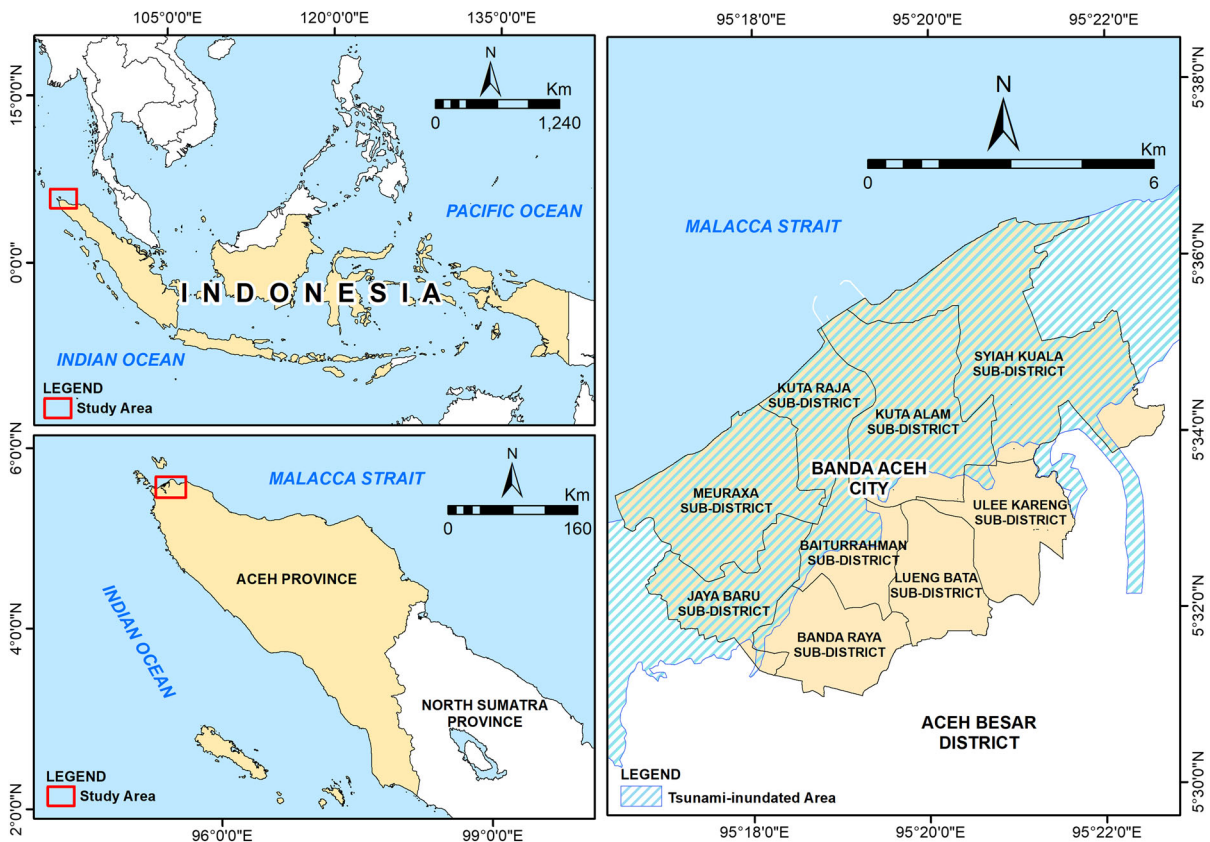


Fig. 1 Study area map

Land cover was classified from Landsat 5 TM (for 2005 and 2009) and Landsat 8 OLI/TIRS (for 2019). The images were downloaded via the United States Geological Survey website and selected with cloud cover criteria < 10%.

Land cover was interpreted with the categories of built-up and non-built-up areas because this study focuses on the morphological–physical characteristics of urban areas. Non-built-up area classes include vegetation, water bodies, bare land, and built-up areas that are completely destroyed by the tsunami. Meanwhile, the built-up areas consist of roads, residential areas, offices, ports, commercial areas, and other building structures.

The method used to classify land cover was supervised classification with maximum likelihood. Before being classified, the satellite images were corrected to improve quality. Image cropping was adjusted to the city administrative boundary shapefile obtained from the Government of Banda Aceh. Furthermore, the training area for each year was collected visually from Google Earth and high-resolution imagery. The land cover classification was carried out using ENVI software. Manual editing was conducted to correct misclassification.

An accuracy assessment was performed for each classified image using the stratified random sampling method with a total sample of 300 validation points. A confusion matrix was used to calculate classification accuracy. The overall accuracy of the classified images reached 89.00% for 2005 and 2009, and 91.67% for 2019. The Kappa coefficient was 0.78 for 2005 and 2009, and 0.83 for 2019. These results are considered feasible to continue for the analysis (Thomlinson et al. 1999; Congalton and Green 2009).

Estimation of urban physical growth rate

The built-up area data in this study were overlaid with the 2004 tsunami inundation area map obtained from the Regional Development Planning Agency (*Bappeda*) of Banda Aceh. This process was done using ArcGIS software. The built-up area within the tsunami-affected and safe areas can be estimated at each analysis period.

Equation (1) was used to quantify annual urban physical growth rates in areas affected by the tsunami and in safe zones. Basically, this metric is a modification of the exponential population growth formula

(Nong et al. 2018). The formula for annual urban physical growth rate is shown as follows:

$$r = \frac{1}{t_2 - t_1} \ln \frac{ULA_i^{t_2}}{ULA_i^{t_1}} \quad (1)$$

where $ULA_i^{t_2}$ and $ULA_i^{t_1}$ are the areas of urban built-up land in unit i in years t_2 and t_1 , respectively.

Identifying driving forces

This section places more emphasis on a qualitative approach. In this study, growth factors were developed from the results of in-depth interviews with five informants. The informants were considered to have adequate knowledge or experience related to the research topic. Rather than discussing the number of informants that is usually debated, saturation is the most important parameter in qualitative studies, although it also depends on many factors (Dworkin 2012; Jarah et al. 2019). Extensive literature reviews (e.g., previous research in the same location, technical reports, government policy reports, and statistical documents) were also conducted to analyze drivers. These reviews act as references in compiling interview questions and as materials in triangulating to ensure validity and reliability.

Interviews were conducted using semi-structured questions with the staff of the Regional Development Planning Agency (*Bappeda*) of Banda Aceh and the staff of the Public Works and Spatial Planning Agency (*Dinas PUPR*) of Banda Aceh as representatives of practitioners, and with the local urban experts from Universitas Syiah Kuala as representatives of academics. Initially, a map of urban physical growth in each period was shown to each informant to obtain a characteristic description. Then, they were asked what the determinants of growth were (with open responses), and the answers were explored further so that they could be understood in depth. The informants were also asked about other possible factor(s) that had not been mentioned (based on literature studies) to reduce bias.

The results of the interviews were recorded with the consent of the participants and transcribed for analysis purposes. These results were analyzed using qualitative descriptive techniques. Before being displayed, data were reduced first to make them simple, focused, and organized, which could affect conclusions or data

interpretation (Miles and Huberman 1994). Various factors that could fall into the same category were considered.

Results

Urban vulnerability toward tsunami disaster

Urban physical growth during 2005–2019 is illustrated in Fig. 2. The built-up data were overlaid with the 2004 tsunami inundation data on the map. This area can be considered hazard zones with the worst-case scenario. Meanwhile, areas in the city that were not shaded were categorized as safe zones.

The distribution of built-up areas in the two zones was compared (Fig. 3). In 2005, the total built-up area in tsunami-affected zones was 799 ha. The area shows the remaining built-up that was not completely destroyed despite being inundated by the 2004

tsunami. Meanwhile, the total built-up area in safe zones was only 628 ha. The built-up areas before the 2004 tsunami were mostly distributed in hazard zones, and many of them experienced total destruction.

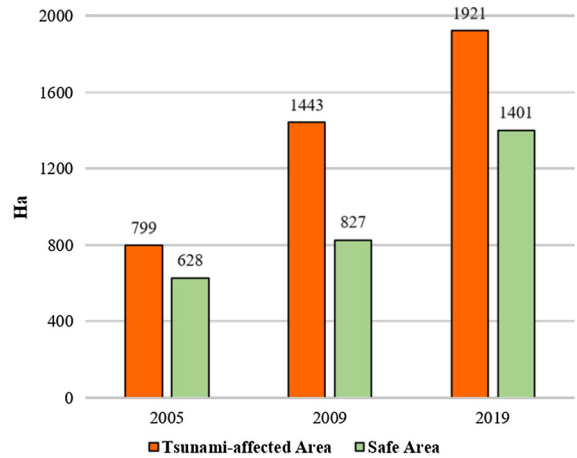


Fig. 3 Built-up area in the tsunami-affected and safe areas

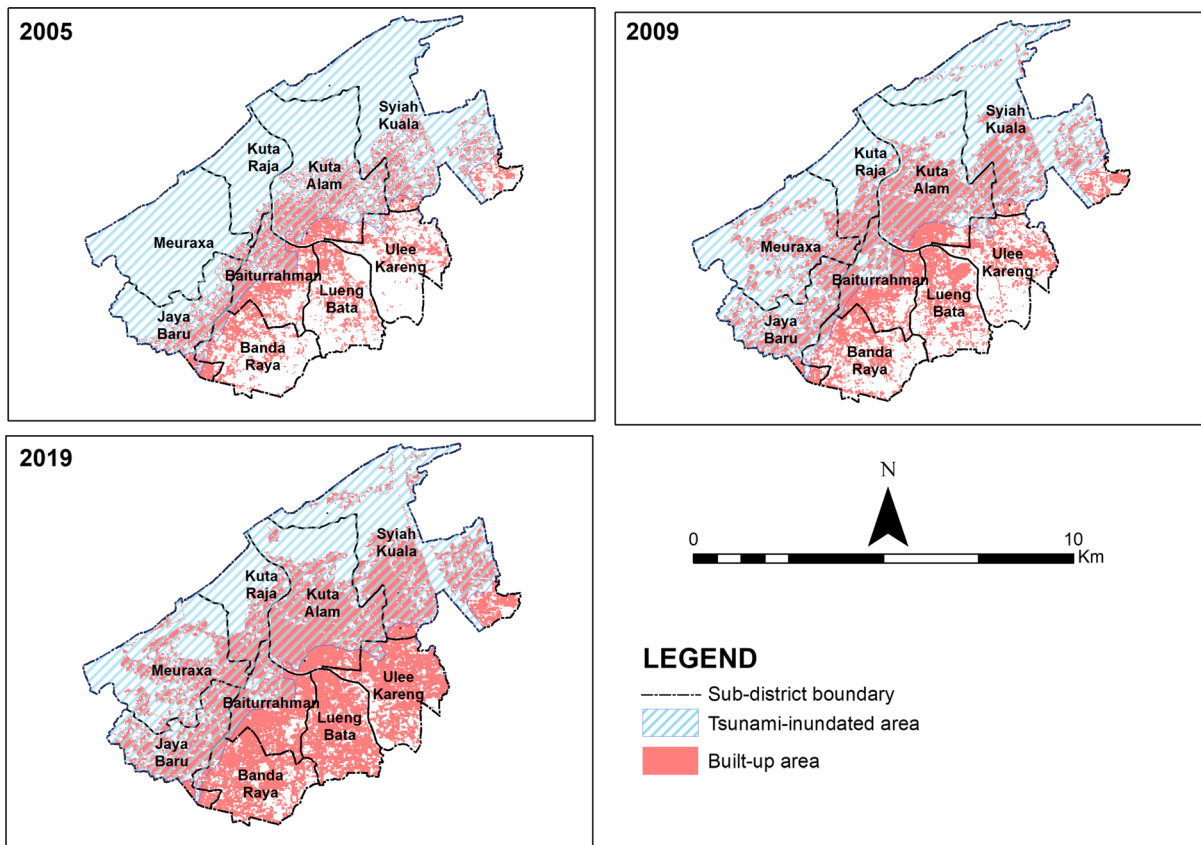


Fig. 2 Built-up distribution in Banda Aceh City

Urban recovery occurred officially from 2005 to 2009. As the reconstruction and rehabilitation period ended, the total built-up area in 2009 was more than 1.5 times that in 2005. The rebuilding at that time was rapid because the disaster recovery focused on physical development. Most of the built-up areas that were destroyed by the 2004 tsunami had been rebuilt in the original place so that the area reached 1443 ha. The total built-up area in safe zones also increased to 827 ha. New infrastructure development occurred in the zones as a step toward preparing a new urban center, which could trigger rapid suburbanization.

The addition of new built-up areas continued until 2019. Nearly 60% of the city area was filled with urban land cover, which made the city more compact. Nevertheless, most of the urban land cover was still in tsunami-affected areas. The total built-up areas in tsunami-affected and safe zones in 2019 were 1921 and 1401 ha, respectively. Peri-urban development is expected to intensify in the future as a consequence of limited land in safe zones of Banda Aceh City.

Urban physical growth rate

Figure 4 shows the annual rate of urban physical growth in both zones during 2005–2019. In general, the annual growth rate in Banda Aceh in 2005–2009 was higher than that in 2009–2019. If viewed from the thematic zones, the growth rate in each period also showed significant differences.

In 2005–2009, the annual growth rates in the tsunami-affected and safe zones were 14.79% and 6.87%, respectively. The growth direction was mainly toward hazard zones. This value also indicates that the

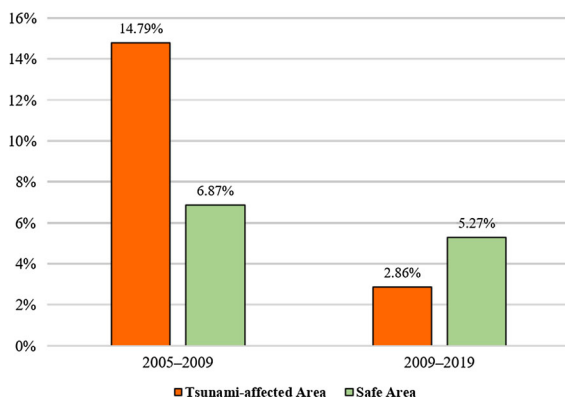


Fig. 4 Built-up growth rate in tsunami-affected and safe areas

urban physical growth in both zones was relatively fast.

Compared with the previous period, the annual growth rate in 2009–2019 was lower in both zones. However, the increase in the new built-up area in safe zones was higher than that in tsunami-affected areas in 2009–2019. The safe zones had the highest annual growth rate, although the rate also declined to 5.27%. The annual growth rate in the tsunami-affected areas dropped significantly with a value of 2.86%. This result shows that the development in Banda Aceh focused on areas safe from tsunami hazards. However, the increase in the built-up area that still occurs in hazard zones needs considerable attention because of the great potential for loss from future disasters.

Key factors of built-up expansion in tsunami-affected areas

The results clearly show that Banda Aceh experienced rapid urban physical growth after the 2004 tsunami. However, most of the built-up areas were still in tsunami-affected areas. The experience of the tsunami does not seem to be a major consideration in urban redevelopment. In particular, the growth intensity in hazard zones was very high during the recovery period. In this case, at least five driving forces of urban physical growth were identified in tsunami-affected areas: (1) population growth, (2) spatial planning, (3) distance to old city center, (4) land ownership and prices, and (5) socio-economic factors. These factors are generally related to one another.

Population growth

Population plays an important role in the expansion of built-up areas because it contributes to the demand for housing and urban services. The dynamics of the population in Banda Aceh after the 2004 tsunami is shown in Fig. 5. The highest population growth rate during 2005–2019 was recorded in sub-districts located on the west coast. Most of the population of Banda Aceh was concentrated in Kuta Alam, Syiah Kuala, and Baiturrahman. It was higher than that in the other three sub-districts which are farther away from the shoreline (Banda Raya, Lueng Bata, and Ulee Kareng). This demographic condition was influenced by factors of strategic location and the existence of important service facilities.

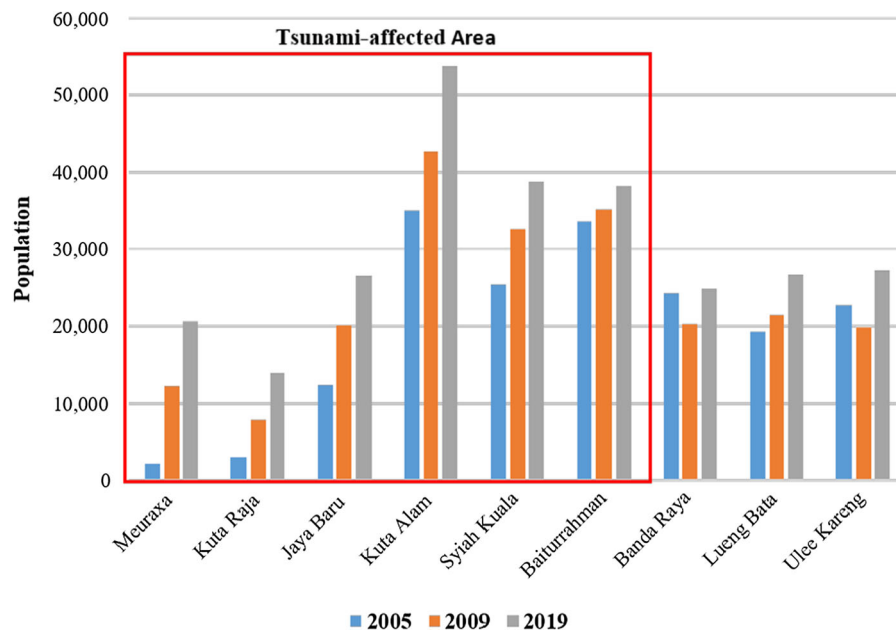


Fig. 5 Population growth dynamics in Banda Aceh City. Source BPS Kota Banda Aceh (2010, 2020)

The population increased significantly in Banda Aceh during the recovery period with a growth rate of 4.5% per year. The rate of population growth was relatively high in tsunami-affected areas, especially in Meuraxa and Kuta Raja. Many tsunami survivors moved from the damaged areas to unaffected regions during the first year. However, the displacement was temporary and many people returned to the coastal areas to claim relief (Mahdi 2012). Thus, return migration during the recovery period played a significant role in resettlement in hazard zones (Syamsidik et al. 2017). Along with the high demand for residents to settle back in coastal areas, development was also carried out on a massive scale. One of the informants explained the reasons behind the rapid development:

Banda Aceh as the capital of Aceh Province attracted the population to come, supported by conditions were already peaceful (post-conflict), and high money turnover during the reconstruction and rehabilitation phase (Interview to expert 1, 29 February, 2020).

A large number of job opportunities and humanitarian assistance provided by the government and non-governmental organizations during the recovery period became a pull factor for urbanization. At the

same time, the resolution of the prolonged conflict between the Government of Indonesia and the separatist group (the Free Aceh Movement) also produced a conducive environment for development. Hence, the large-scale recovery has induced higher economic growth in Banda Aceh (Achmad et al. 2014).

The population growth in Banda Aceh in 2009–2019 was lower than that in the previous period (2.4% per year). However, the population growth in areas affected by the tsunami was still relatively high, which was likely to be more influenced by the rate of migration to the city (Syamsidik et al. 2017). Combined with natural growth, the population in hazard zones is expected to continue to increase.

The local community had been given the choice to be relocated or resettled in their original locations. However, many of them chose not to be relocated and urged immediate rebuilding in tsunami-affected areas. It was also difficult for the government to relocate all residents from the coastal areas because of considerations of land availability, property rights, compensation costs, and land acquisition (Fahmi et al. 2014). The Reconstruction and Rehabilitation Agency (BRR) and donor agencies were pursued by the target to immediately build houses so that costs could be minimized. As a result, construction was continued in

areas affected by the tsunami in accordance with the community requests.

Spatial planning

Spatial planning is an important tool for achieving sustainable land management. A series of planning improvisation has been carried out to create a city that is safer from the tsunami. Immediately after the 2004 tsunami disaster, the National Development Planning Agency (*Bappenas*) and the Reconstruction and Rehabilitation Agency (BRR) revised the previous spatial planning document (Qanun No. 3/2003) and accelerated recovery efforts through the Master Plan for the Rehabilitation and Reconstruction of Aceh and Nias. The results of the planning at the early stage produced a new document called Blue Print. The Japan International Cooperation Agency (JICA) also facilitated the recovery process and designed the Master Plan document specifically for the Banda Aceh urban area through the Urgent Rehabilitation and Reconstruction Plan for Banda Aceh City.

The Blue Print contains a buffer zone as far as ± 2 km from the shoreline. Development was prohibited within the zone, except housing for fishermen with scattered patterns. However, the community did not approve of the plan because many of them would be relocated if it was implemented (JICA 2005; Danar and Pushpalal 2014; Maynard et al. 2018). Only a portion of the community was willing to be relocated, especially for those who were severely traumatized and whose land was no longer suitable for use.

Meanwhile, a bottom-up-based reconstruction plan called Village Plan was initiated by the United States Agency for International Development and other donor agencies in March 2005. The plan accommodated more the aspirations of the community when compared with the Blue Print formulation process. The community wanted to rebuild settlements in the same location. As a result, the areas that were inundated by the tsunami were rebuilt. One of the informants also admitted that there was a failure in implementing the initial strategy:

In the Blue Print, urban settlements were not designed to be built on the coastal areas, but in fact one of the fastest growing housing

developments was found there (Interview to expert 2, 12 March, 2020).

The concept is different from the concepts in Blue Print. In the end, JICA considered it in the Master Plan to reconstruct residential areas with additional mitigation measures, such as evacuation road widening, installation of disaster signs, and construction of evacuation buildings (JICA 2005; Matsumaru et al. 2012). The concept subsequently became a reference in the new spatial planning draft (Qanun No. 4/2009) that was published in 2009.

Distance to old city center

The new spatial planning established a new main center in the southern part of the city so that development can be directed away from the tsunami hazard (Fig. 6). However, the old city center and its surrounding area still had a relatively high building density. This phenomenon was also examined in previous studies using quantitative modeling, where urban physical growth in Banda Aceh was strongly influenced by the distance to the old city center, especially during the recovery period (Achmad et al. 2015). Interviews revealed that rebuilding around the old city center cannot be avoided, even though it was inundated by the 2004 tsunami. One of the informants posited that:

We are trying to build a new town far from the coast. We let the construction around the old city center. Trading activities cannot be prohibited there (Interview to *Bappeda* staff, 5 March, 2020).

The old city center was still appealing for the people. It has long been a central business district and has high historical value with the Baiturrahman Grand Mosque as a city landmark. The old main center still functions for regional trade and government activities after the 2004 tsunami so that the population is attracted to resettle in the surrounding areas, which is possibly become a driver of the built-up growth in tsunami-affected areas. Most of the damaged roads and facilities were repaired or rebuilt at the original location. Accessibility of transportation and public services plays an important role in the built-up expansion. Its strategic position and proximity to

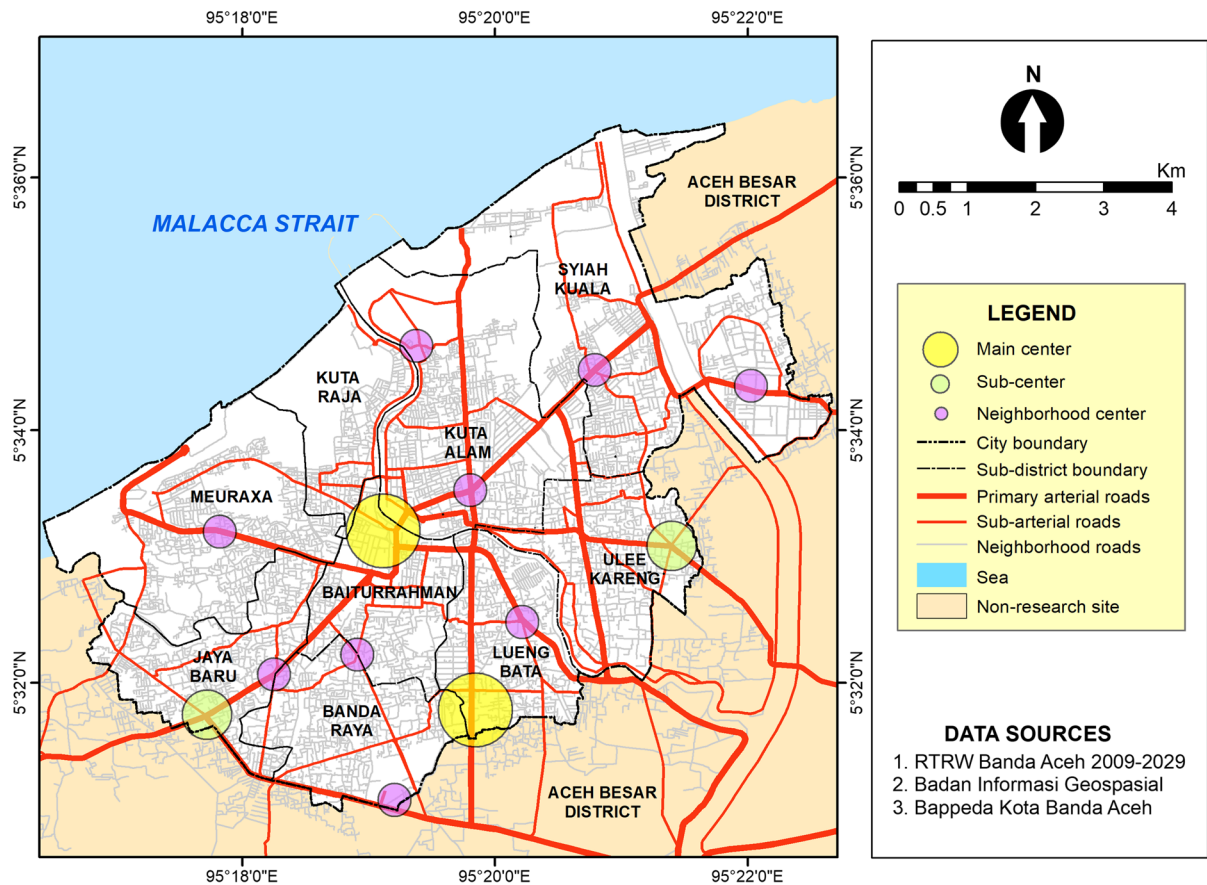


Fig. 6 Map of the structure of Banda Aceh City

various urban facilities also contribute to its redevelopment.

Land ownership and prices

Land is the main capital that must be owned by the community to construct buildings. The influence of land ownership on the decision to select living places was stated by an informant:

Some people only own land there (tsunami-affected area). Finding new land was costly so they struggled to build again (Interview to Bappeda staff, 5 March, 2020).

People who own land in a coastal area tend to settle in that location, especially if they have no land other than those in tsunami-affected areas (Siregar et al. 2019). The city government is also having difficulty relocating the community because of the limited availability

of land in other places. Another important consideration is the prices of land.

Land prices between the coastal areas and inland did not differ significantly before the 2004 tsunami. The large-scale disaster in 2004 had caused significant changes in land prices between the coastal region and the city inland. Land prices in safe zones were expensive, whereas those in tsunami-affected areas (not including the city center) are affordable. A study conducted by McCaughey et al. (2018) in Banda Aceh showed that land prices in the inland are currently on average 2.1 times the prices of land in tsunami-affected areas. This scenario was also followed by an increasingly higher gap in the purchase and rental prices of houses in both areas. The cause of post-tsunami land price changes was stated by one of the informants:

Now many people live here (coastal zone). The land prices are cheaper because the area was

classified as a former tsunami inundation. In the south, the prices are higher due to high demand for land (Interview to *Dinas PUPR* staff, 6 March, 2020).

The increase in land prices in the city inland is a consequence of the increased demand to make housing in areas unaffected by the tsunami, coupled with the government's priority development policy to the south. Meanwhile, the coastal zone has lower land prices because it was affected by tsunami inundation and was directed as a conservation area. This change is in accordance with the law of demand and supply in economics. Therefore, land prices become a pull factor for the people, especially for low-income groups, to settle in hazard zones (Syamsidik et al. 2017).

Socio-economic factors

The tsunami disaster has caused long-term impacts on socio-economic conditions in Banda Aceh. Several studies reported that household livelihoods have not fully returned to their pre-tsunami levels, even though people have implemented adaptive strategies supported by various aid programs (Ismail et al. 2018; Daly et al. 2020). On the basis of interviews, the poverty rates in tsunami-affected areas are higher than those in areas far from the coast at present. Changes in the characteristics of poverty during pre-tsunami and post-recovery have also been identified by previous research (McCaughey et al. 2018).

Along with the significant rise in property prices in the inland, low-income groups do not have access to move from hazard zones. This finding is in accordance with the research of McCaughey et al. (2018) which also shows that tsunami survivors who migrate to the inland tend to have better socio-economic status than those living in tsunami-affected areas. In addition, aid houses left by their owners are often targeted by poor migrants for purchase or rent at low prices:

There are rich people affected by the tsunami who get aid houses in the coastal areas. He/she can move to safe zones. Then, the house was bought by someone (migrant) who was poorer than him/her so that an exchange occurred (Interview to expert 1, 29 February, 2020).

However, resettlement in areas affected by the tsunami is not only determined by socio-economic status. It is also influenced by various reasons, one of which relates to community livelihoods. Coastal areas have long been utilized for fisheries and aquaculture. Coastal communities have strong links with the sea. In addition, the trade and service center also exists in the northern part of the city. Therefore, many people choose to rebuild settlements in the tsunami-affected areas because of their proximity to the workplace (Syamsidik et al. 2017).

The tsunami-affected areas still have a high historical and cultural value for the local community. Their land was obtained from the family inheritance. They also have strong capital and social connections, which also played an important role in the high rate of return migration to tsunami-affected areas (da Silva 2010). One informant stated that people can get satisfaction by reoccupying the same site. This shows the importance of the sense of place as a motivation to resettle at the place of origin:

If the damaged house was reconstructed on its own site, it seemed that despite the trauma, there was some kind of nostalgia that could be rebuilt (Interview to expert 3, 2 March, 2020).

In addition, some people have the mindset of “boil will not grow in the same place”. They still believe that the tsunami will not happen again, but if it will, then it is the will of God. Danar and Pushpalal (2014) stated that the belief factor influences the resettlement process in the city of Banda Aceh. It also possibly contributed to the psychological recovery of the survivors.

The statements above prove that resettlement is not only a process of building a place to live but also relates to livelihoods. This condition is different if they were relocated to other places because they had to build social networks from an early stage and adapt to new activities to ensure the fulfillment of basic needs. Some relocation sites are located in the hills and far from the city center. Thus, relocation can sometimes introduce tsunami survivors to new risks of other types of disasters (e.g., landslides) and livelihoods (Vale et al. 2014; Sina et al. 2019). As expected, some of the people who have been relocated returned to their original places of residence because they feel uncomfortable or unsatisfied with their new homes.

Discussion

Future challenges for tsunami risk reduction

The 2004 Indian Ocean Tsunami provided new lessons for disaster risk reduction. Nevertheless, efforts to reduce tsunami risk in Banda Aceh still face major challenges, especially urban expansion in areas affected by the tsunami. Many settlements, infrastructures, and commercial areas have been rebuilt in tsunami-affected areas (Fig. 7). Building back better-based urban development has not yet been fully achieved, although the direction of development dominates more into safe zones after the recovery period ends. Urban vulnerability to tsunamis is still very high or can even match conditions before the 2004 tsunami.

These results support the report by Meilianda et al. (2017) that Banda Aceh City failed to utilize the windows of opportunity to achieve BBB. This phenomenon was particularly apparent during the rehabilitation and reconstruction period, where the rate of urban physical growth in the tsunami-affected areas was high. Instead of reaching the BBB, rebuilding in this region focused on building back faster (Kennedy et al. 2008). Interviews showed that the concept of disaster prevention offered during the initial phase of recovery (i.e., buffer zone) was unrealistic to be

applied. This correlates with the statement of McCaughey et al. (2018) that decisions to rebuild post-disaster lead to a tradeoff. Mass relocation from tsunami-affected areas can lead to social disruption, whereas in situ development can re-create high risks.

As a geomorphological phenomenon, tsunami can occur many times in an area. The 2004 tsunami was not the first catastrophic tsunami on the northern coast of Aceh. A recent study has shown that the same large-scale disaster destroyed the coastal settlements around Banda Aceh in the late 14th century based on archaeological evidence (Daly et al. 2019). This finding was predicted to be related to the results of previous work in the form of paleotsunami and paleogeodetic data of the same age range obtained in various locations on the coast of Aceh (Monecke et al. 2008; Meltzner et al. 2010; Sieh et al. 2015). Large-scale tsunamis can occur again in the future, especially with consideration of its position in the active seismic zone. A seismic gap zone has been identified on the west coast of Sumatra so that Banda Aceh is classified as one of the priority areas to anticipate tsunami caused by large magnitude earthquake (Jihad et al. 2020). The potential for rising sea levels in the future can even worsen the impacts of tsunami in the Banda Aceh coastal region (Meilianda et al. 2019).

Reflecting on the potential for future tsunamis, efforts to reduce risk must still be carried out. The



Fig. 7 Field documentation of built-up areas in hazard zones

BBB concept has been adopted in spatial planning, such as the application of the multi-center city concept, the construction of evacuation roads and buildings, and restrictions on development in coastal areas. This progress will be useful for improving disaster management since urban planning before the 2004 tsunami (Qanun No. 3/2003) did not consider the tsunami hazard. However, some additional mitigation efforts are needed to improve the effectiveness of disaster risk reduction.

Recently, the Banda Aceh City spatial planning document has been revised in accordance with Qanun No. 2/2018. This revision was performed to adjust to the existing development dynamics. Document analysis showed several changes, such as the establishment of a new strategic area in southern Syiah Kuala, a shift in the position of the sub-center in Jaya Baru, changes in land use patterns zonation, and others that also include details of land utilization. Flyover and underpass construction plans designed to minimize traffic problems can be useful as evacuation routes. Disaster susceptibility map (including tsunami) has become an inseparable part of the document, and general provisions have been made for activities in hazard zones, although inconsistencies are still found between the results of policy formulation and implementation. One of the problematic issues most emphasized by urban authorities from the planning revision relates to coastal green open spaces. Rapid development is found in some of these areas that have been determined in previous planning (Qanun No. 4/2009), especially on private land, so that adjustments are needed. This scenario indicates a weakness of the spatial planning implementation in controlling urban expansion in hazard zones.

A new spatial planning document is also formally planning the construction of the Banda Aceh Outer Ring Road (BORR) along the city's coastal areas. The development is expected to control land use while reducing the level of traffic congestion. Previous studies suggested that the construction of an elevated BORR can reduce the area of inundation, height, and velocity of tsunami waves (Syamsidik et al. 2019). However, one informant is concerned that the development will trigger urban growth in hazard zones. Other problems that can arise are extensive shrinkage of mangroves due to development, increased ownership of private vehicles, and economic infeasibility (Rizkiya 2012). Apart from the debate, restrictions on

development must be carried out strictly in areas affected by the tsunami. Such restrictions include conserving wetlands and implementing buy-back schemes on high-risk lands.

The scenario of buying land owned by the community in high-risk areas has been declared by the government. However, the government (i.e., *Bappeda* and *Dinas PUPR*) stated that they could not buy all the land to be acquired because of limited funds. This problem is also commonly found in other cities in Indonesia. The placement of green open space on community-owned land does not provide economic benefits for land-owners because it is left unused. In fact, green open space is an important component in an urban environment because of its several benefits in ecological processes (e.g., micro-climate control, water catchment areas, and habitat providers) and disaster mitigation. The land certainly has the potential to be built as a settlement in the future if it is not well controlled. Therefore, an urban expert suggested the need for a paradigm shift in the management of green open space in the coastal region that is also concerned with economic profit while maintaining the sustainability of the ecosystem. This process requires good cooperation between stakeholders. Finally, increasing public awareness is the key to successful tsunami risk reduction in urban areas.

Conclusion

This study investigated the dynamics of urban physical growth in Banda Aceh City after the 2004 Indian Ocean Tsunami. In general, the total built-up area in tsunami-affected areas has continued to increase. The rate of urban built-up expansion in tsunami-affected areas was fast during the disaster recovery period (2005–2009). In the next period (2009–2019), the intensity of urban physical growth decreased as the city became more compact. Urban development was directed toward safe zones, as supported by the establishment of a new city center in safe zones and the construction of new infrastructures toward the southern and eastern parts of the city.

Despite the positive trend in recent urban developments, most of the built-up areas are in the hazard zones. This result shows that urban vulnerability to tsunamis in Banda Aceh is still high. Opportunities to reach BBB have not been well achieved. The

rebuilding in this area is influenced by several complex factors, such as population growth, spatial planning, distance to old city center, land ownership and prices, and socio-economic factors. This condition became a major challenge for governments and decision-makers in reducing urban disaster risk. Therefore, further tsunami mitigation strategies need to be undertaken to anticipate potential future tsunami.

This research has important implications for sustainable urban development, which also has a strong relationship with BBB. Urban planning is a key tool for shaping urban resilience. A multi-risk analysis also needs to be considered. Failure to formulate and implement appropriate policies can lead to undesirable consequences in the future. This paper also recommends the need for effective urban growth management in the outskirts of Banda Aceh City as development intensifies in safe zones.

Acknowledgements The authors would like to thank Dr. Djaka Marwasta and Dr. Rini Rachmawati for their meaningful suggestions to improve this paper.

Author's contributions IA contributed to conceptualization, formulated the research design, coordinated the data collection, performed the analysis and interpreted the data, and drafted the manuscript. SRG participated in the research design and helped to draft the manuscript. All authors read and approved the final manuscript.

Funding The authors received no specific funding for this work.

Availability of data and material The data used is with the authors and can be available upon demand.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

- Achmad, A., Hasyim, S., Rangkuti, B., & Aulia, D. N. (2015). Spatial relationship between city center and economic activity center on urban growth in tsunami-prone city: The case of Banda Aceh, Indonesia. *Jurnal Teknologi*, 75(1), 47–53. <https://doi.org/10.11113/jt.v75.2653>.
- Achmad, A., Sirojuzilam, Badaruddin, Achmad, A., & Aulia, D. N. (2014). Analysis of urban growth pattern and socio-economic aspect after the tsunami disaster: The case of Banda Aceh, Aceh, Indonesia. *International Journal of Research in Engineering and Technology*, 3(1), 428–435. <https://doi.org/10.15623/ijret.2014.0301074>.
- ADPC. (2013). *Integrating disaster risk management into urban management*. Bangkok: ADPC.
- Amri, I. (2020). *Analisis pertumbuhan fisik perkotaan di Banda Aceh pasca-Tsunami Samudra Hindia 2004*. Thesis, Yogyakarta: Universitas Gadjah Mada.
- Amri, I., & Giyarsih, S. R. (2020). Quantifying urban physical growth types in Banda Aceh City after the 2004 Indian Ocean Tsunami. *E3S Web of Conferences*, 200, 07003. <https://doi.org/10.1051/e3sconf/202020007003>.
- Arief, M. C. W., & Itaya, A. (2018). Influence of the 2004 Indian Ocean Tsunami recovery process on land use and land cover in Banda Aceh, Indonesia. *Journal of Forest Planning*, 22(2), 55–61. https://doi.org/10.20659/jfp.22.2_55.
- Arikawa, T., Muhari, A., Okumura, Y., Dohi, Y., Afriyanto, B., Sujatmiko, K. A., et al. (2018). Coastal subsidence induced several tsunamis during the 2018 Sulawesi Earthquake. *Journal of Disaster Research*, 13, sc20181204. <https://doi.org/10.20965/jdr.2018.sc20181204>.
- Asian Development Bank. (2016). *Reducing disaster risk by managing urban land use: Guidance notes for planners*. Manila: Asian Development Bank.
- BPS Kota Banda Aceh. (2010). *Banda Aceh Dalam Angka 2010*. Banda Aceh: BPS Kota Banda Aceh.
- BPS Kota Banda Aceh. (2020). *Kota Banda Aceh Dalam Angka 2020*. Banda Aceh: BPS Kota Banda Aceh.
- Chang, S. E., Gregorian, M., Pathman, K., Yumagulova, L., & Tse, W. (2012). Urban growth and long-term changes in natural hazard risk. *Environment and Planning A*, 44(4), 989–1008. <https://doi.org/10.1068/a43614>.
- Clinton, W. J. (2006). *Lesson learned from tsunami recovery: Key propositions for building back better. Report*. New York, NY: United Nations Secretary-General's Special Envoy for Tsunami Recovery.
- Coburn, A. W., Evan, T., Foulser-Piggott, R., Kelly, S., Ralph, D., Ruffle, S. J., et al. (2015). *World city risk 2025: Part I overview and results*. Cambridge: Cambridge Centre for Risk Studies.
- Congalton, R. G., & Green, K. (2009). *Assessing the accuracy of remotely sensed data: Principles and practices*. Boca Raton, FL: CRC Press.
- da Silva, J. (2010). *Lessons from Aceh: Key considerations in post-disaster reconstruction*. Warwickshire: Practical Action Publishing.
- Daly, P., Mahdi, S., McCaughey, J., Mundzir, I., Halim, A., Nizamuddin, Ardiansyah, et al. (2020). Rethinking relief, reconstruction and development: Evaluating the effectiveness and sustainability of post-disaster livelihood aid. *International Journal of Disaster Risk Reduction*, 49, 101650. <https://doi.org/10.1016/j.ijdr.2020.101650>.
- Daly, P., Sieh, K., Seng, T. Y., McKinnon, E. E., Parnell, A. C., Ardiansyah, et al. (2019). Archaeological evidence that a late 14th-century tsunami devastated the coast of Northern Sumatra and redirected history. *Proceedings of the National Academy of Sciences*, 116(24), 11679–11686. <https://doi.org/10.1073/pnas.1902241116>.
- Danar, O. R., & Pushpalal, D. (2014). Building community resilience: Conceptual framework and its application in post tsunami resettlement. *Procedia Economics and*

- Finance*, 18, 489–496. [https://doi.org/10.1016/S2212-5671\(14\)00967-8](https://doi.org/10.1016/S2212-5671(14)00967-8).
- Dickson, E., Baker, J. L., Hoomweg, D., & Tiwari, A. (2012). *Urban risk assessments: Understanding disaster and climate risk in cities*. Washington, DC: The World Bank.
- Djalante, R., Thomalla, F., Sinapoy, M. S., & Carnegie, M. (2012). Building resilience to natural hazards in Indonesia: Progress and challenges in implementing the Hyogo Framework for Action. *Natural Hazards*, 62(3), 779–803. <https://doi.org/10.1007/s11069-012-0106-8>.
- Dworkin, S. L. (2012). Sample size policy for qualitative studies using in-depth interviews. *Archives of Sexual Behavior*, 41(6), 1319–1320. <https://doi.org/10.1007/s10508-012-0016-6>.
- EM-DAT. (2019). Disaster list. URL: https://www.emdat.be/emdat_db/. Accessed 20 August 2019.
- Fahmi, F., Timms, P., & Shepherd, S. (2014). Integrating disaster mitigation strategies in land use and transport plan interaction. *Procedia – Social and Behavioral Sciences*, 111, 488–497. <https://doi.org/10.1016/j.sbspro.2014.01.082>.
- Farrell, K. (2017). The rapid urban growth triad: A new conceptual framework for examining the urban transition in developing countries. *Sustainability*, 9(8), 1407. <https://doi.org/10.3390/su9081407>.
- Fernandez, G., & Ahmed, I. (2019). “Build back better” approach to disaster recovery: Research trends since 2006. *Progress in Disaster Science*, 1, 100003. <https://doi.org/10.1016/j.pdisas.2019.100003>.
- Ghobarah, A., Saatcioglu, M., & Nistor, I. (2006). The impact of the 26 December 2004 Earthquake and Tsunami on structures and infrastructure. *Engineering Structures*, 28(2), 312–326. <https://doi.org/10.1016/j.engstruct.2005.09.028>.
- Gu, D. (2019). Exposure and vulnerability to natural disasters for world’s cities. *Population Division Technical Paper No. 2019/4*. New York, NY: United Nations.
- Guadagno, L., Depietri, Y., & Paleo, U. F. (2013). Urban disaster risk reduction and ecosystem services. In F. G. Renaud, et al. (Eds.), *The role of ecosystems in disaster risk reduction* (pp. 389–415). Tokyo: UNU Press.
- Hamdy, O., Zhao, S., Salheen, M. A., & Eid, Y. Y. (2016). Identifying the risk areas and urban growth by ArcGIS-tools. *Geosciences*, 6(4), 47. <https://doi.org/10.3390/geosciences6040047>.
- Huang, Q., Meng, S., He, C., Dou, Y., & Zhang, Q. (2019). Rapid urban land expansion in earthquake-prone areas of China. *International Journal of Disaster Risk Science*, 10(1), 43–56. <https://doi.org/10.1007/s13753-018-0207-4>.
- Ismail, N., Okazaki, K., Ochiai, C., & Fernandez, G. (2018). Livelihood Strategies after the 2004 Indian Ocean Tsunami in Banda Aceh, Indonesia. *Procedia Engineering*, 212, 551–558. <https://doi.org/10.1016/j.proeng.2018.01.071>.
- Iuchi, K., & Esnard, A. (2008). Earthquake impact mitigation in poor urban areas: The case of Metropolitan Manila. *Disaster Prevention and Management*, 17(4), 454–469. <https://doi.org/10.1108/09653560810901700>.
- Jarah, S. H. A., Zhou, B., Abdullah, R. J., Lu, Y., & Yu, W. (2019). Urbanization and urban sprawl issues in city structure: A case of the Sulaymaniah Iraqi Kurdistan Region. *Sustainability*, 11(2), 485. <https://doi.org/10.3390/su11020485>.
- JICA. (2005). *The study on the urgent rehabilitation and reconstruction support program for Aceh province and affected areas in North Sumatra (urgent rehabilitation and reconstruction plan for Banda Aceh city)*. Final Report (1). Vol. II: Main Report. Banda Aceh and Tokyo: JICA.
- Jihad, A., Muksin, U., Syamsidik, Suppasri, A., Ramli, M., & Banyunegoro, V. H. (2020). Coastal and settlements typologies-based tsunami modeling along the northern Sumatra seismic gap zone for disaster risk reduction action plans. *International Journal of Disaster Risk Reduction*, 51, 101800. <https://doi.org/10.1016/j.ijdr.2020.101800>.
- Kennedy, J., Ashmore, J., Babister, E., & Kelman, I. (2008). The meaning of ‘build back better’: Evidence from post-tsunami Aceh and Sri Lanka. *Journal of Contingencies and Crisis Management*, 16(1), 24–36. <https://doi.org/10.1111/j.1468-5973.2008.00529.x>.
- Khazai, B., Daniell, J. E., & Wenzel, F. (2011). The March 2011 Japan Earthquake: Analysis of losses, impacts, and implications for the understanding of risks posed by extreme events. *TATuP—Zeitschrift für Technikfolgenabschätzung in Theorie Und Praxis*, 20(3), 22–33. <https://doi.org/10.14512/tatup.20.3.22>.
- Mahdi, S. (2012). Faktor-faktor penentu pergerakan pengungsi (IDP) di Aceh. In P. Daly, et al. (Eds.), *Aceh pascatsunami dan pascakonflik* (pp. 149–174). Denpasar: Pustaka Larasan.
- Mannakkara, S., & Wilkinson, S. (2012). ‘Build back better’ principles for land-use planning. *Proceedings of the Institution of Civil Engineers—Urban Design and Planning*, 166(5), 288–295. <https://doi.org/10.1680/udap.12.00017>.
- Matsumaru, R., Nagami, K., & Takeya, K. (2012). Reconstruction of the Aceh region following the 2004 Indian Ocean Tsunami disaster: A transportation perspective. *IATSS Research*, 36(1), 11–19. <https://doi.org/10.1016/j.iatssr.2012.07.001>.
- Matsuoka, Y., Sharma, A., & Shaw, R. (2009). Hyogo Framework for Action and urban risk reduction in Asia. In R. Shaw, et al. (Eds.), *Urban risk reduction: An Asian perspective* (pp. 77–104). Bingley: Emerald Group Publishing Limited. [https://doi.org/10.1108/S2040-7262\(2009\)0000001009](https://doi.org/10.1108/S2040-7262(2009)0000001009).
- Maynard, V., Parker, E., Yoseph-Paulus, R., & Garcia, D. (2018). Urban planning following humanitarian crises: Supporting urban communities and local governments to take the lead. *Environment and Urbanization*, 30(1), 265–282. <https://doi.org/10.1177/0956247817732727>.
- McCaughey, J. W., Daly, P., Munder, I., Mahdi, S., & Patt, A. (2018). Socio-economic consequences of post-disaster reconstruction in hazard-exposed areas. *Nature Sustainability*, 1(1), 38–43. <https://doi.org/10.1038/s41893-017-0002-z>.
- Meilianda, E., Munadi, K., Azmeri, Safrida, Direzkia, Y., Syamsidik, et al. (2017). Assessment of post-tsunami disaster recovery of Banda Aceh city of Indonesia as window of opportunities for sustainable development. *IOP Conference Series: Earth and Environmental Sciences*, 56(1), 012019. <https://doi.org/10.1088/1755-1315/56/1/012019>.
- Meilianda, E., Pradhan, B., Syamsidik, Comfort, L. K., Alfian, D., Juanda, R., et al. (2019). Assessment of post-tsunami disaster land use/land cover change and potential impact of future sea-level rise to low-lying coastal areas: A case

- study of Banda Aceh coast of Indonesia. *International Journal of Disaster Risk Reduction*, 41, 101292. <https://doi.org/10.1016/j.ijdrr.2019.101292>.
- Meltzner, A. J., Sieh, K., Chiang, H. W., Shen, C. C., Suwargadi, B. W., Natawidjaja, D. H., Philibosian, B. E., Briggs, R. W., & Galetzka, J. (2010). Coral evidence for earthquake recurrence and an A.D. 1390–1455 cluster at the south end of the 2004 Aceh–Andaman rupture. *Journal of Geophysical Research: Solid Earth*, 115(B10). <https://doi.org/10.1029/2010JB007499>.
- Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis* (2nd ed.). Thousand Oaks, CA: Sage Publications.
- Monecke, K., Finger, W., Klarer, D., Kongko, W., McAdoo, B. G., Moore, A. L., et al. (2008). A 1000-year sediment record of tsunami recurrence in northern Sumatra. *Nature*, 455(7217), 1232–1234. <https://doi.org/10.1038/nature07374>.
- Nong, D. H., Lepczyk, C. A., Miura, T., & Fox, J. M. (2018). Quantifying urban growth patterns in Hanoi using landscape expansion modes and time series spatial metrics. *PLoS ONE*, 13(5), e0196940. <https://doi.org/10.1371/journal.pone.0196940>.
- Rimal, B., Zhang, L., Fu, D., Kunwar, R., & Zhai, Y. (2017). Monitoring urban growth and the Nepal Earthquake 2015 for sustainability of Kathmandu Valley, Nepal. *Land*, 6(2), 42. <https://doi.org/10.3390/land6020042>.
- Rizkiya, P. (2012). *The impact of Tsunami 2004 to the urban setting of Banda Aceh*. Master thesis, Frankfurt am Main: The Frankfurt University of Applied Sciences.
- Rizzi, P., & Porębska, A. (2020). Towards a revised framework for participatory planning in the context of risk. *Sustainability*, 12(14), 5539. <https://doi.org/10.3390/su12145539>.
- Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, 109(40), 16083–16088. <https://doi.org/10.1073/pnas.1211658109>.
- Sieh, K., Daly, P., McKinnon, E. E., Pilarczyk, J. E., Chiang, H. W., Horton, B., et al. (2015). Penultimate predecessors of the 2004 Indian Ocean tsunami in Aceh, Sumatra: Stratigraphic, archeological, and historical evidence. *Journal of Geophysical Research: Solid Earth*, 120(1), 308–325. <https://doi.org/10.1002/2014JB011538>.
- Sina, D., Chang-Richards, A. Y., Wilkinson, S., & Potangaroa, R. (2019). A conceptual framework for measuring livelihood resilience: Relocation experience from Aceh, Indonesia. *World Development*, 117, 253–265. <https://doi.org/10.1016/j.worlddev.2019.01.003>.
- Siregar, M. I., Dawood, T. C., Fakhruddin, Rizki, C. Z., Fitriyani, & Reza, M. (2019). Why tsunami survivors remain living in the same location? Evidences from Lampulo Village, Banda Aceh. *IOP Conference Series: Earth Environmental Science*, 273(1), 012060. <https://doi.org/10.1088/1755-1315/273/1/012060>.
- Syamsidik, Oktari, R. S., Munadi, K., Arief, S., & Fajri, I. Z. (2017). Changes in coastal land use and the reasons for selecting places to live in Banda Aceh 10 years after the 2004 Indian Ocean Tsunami. *Natural Hazards*, 88(3), 1503–1521. <https://doi.org/10.1007/s11069-017-2930-3>.
- Syamsidik, Tursina, Suppasri, A., Alala, M., Luthfi, M., & Comfort, L. K. (2019). Assessing the tsunami mitigation effectiveness of the planned Banda Aceh Outer Ring Road (BORR), Indonesia. *Natural Hazards and Earth System Sciences*, 19(1), 299–312. <https://doi.org/10.5194/nhess-19-299-2019>.
- Thomlinson, J. R., Bolstad, P. V., & Cohen, W. B. (1999). Coordinating methodologies for scaling landcover classifications from site-specific to global: Step toward validating global map products. *Remote Sensing of Environment*, 70(1), 16–28. [https://doi.org/10.1016/S0034-4257\(99\)00055-3](https://doi.org/10.1016/S0034-4257(99)00055-3).
- Tyas, W. P. (2018). Living in prone flooding area: In coastal areas of Semarang. *IOP Conference Series: Earth Environmental Science*, 123(1), 012010. <https://doi.org/10.1088/1755-1315/123/1/012010>.
- Umitsu, M., Tanavud, C., & Patanakanog, B. (2007). Effects of landforms on tsunami flow in the plains of Banda Aceh, Indonesia, and Nam Khem, Thailand. *Marine Geology*, 242(1), 141–153. <https://doi.org/10.1016/j.margeo.2006.10.030>.
- United Nations. (2019). *World urbanization prospects: The 2018 revision*. New York, NY: United Nations.
- Vale, L., Shamsuddin, S., & Goh, K. (2014). Tsunami + 10: Housing Banda Aceh after disaster. *Places Journal*. <https://doi.org/10.22269/141215>.

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